EVALUATION OF MANUFACTURABILITY FOR THE EFFECTIVE DECOMPOSITION OF PRODUCT WHEN LAYERED BUILD

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Abstract: The possibility of evaluating the manufacturability of product on the basis of a statistical analysis of the elementary volumes distribution of original 3D model is considered. The proposed indicator allows for quantitative evaluation of the efficiency of applying structural reversible decomposition of a product in order to rationally place it in the workspace of layered build of additive technology installation. The definition of manufacturability index is carried out according to the proposed algorithm for analyzing the distribution of product material in workspace. The algorithm is performed by using voxel 3D-model of product. Approbation of the proposed evaluation algorithm is performed on the example of test models of industrial products. The estimated data for determining the manufacturability level is presented depending on division parts number of workspace with the product. The results show sufficiently high degree of confidence and informative for development of design and technological preparation of additive manufacturing of complex products.

Keywords: additive manufacturing; DFAM; 3D-model; manufacturability.

Formulation of problem

Evaluation of product design for adaptability to the solution of optimization tasks of technological preparation of additive production is of interest for ensuring the highest efficiency of layered manufacturing [1]. One of the main tasks of technological preparation is the structural reversible decomposition of product. Usually decomposition is used for large-sized products, the dimensions of which exceed the dimensions of installation platform [2]. The solution of this problem allows reducing production time and increasing the efficiency of using the volume of working area of installation [3].

Analysis of literature

Structural decomposition is the first task that is performed during technological preparation of layered manufacturing because it determines the geometric and technological constraints which are taken into account when solving subsequent tasks. Such a task is usually solved on basis of the following criteria [3-5]:

- build time;
- products height loaded into working space of installation;
- relative volume occupied by products in the working space;

The product is decomposed in one of the following ways of dissecting the original 3D-model:

- parallel planes in chosen direction [3];
- formation of parts with a minimum of geometrical complexity of surfaces [2, 4, 6] (detailed analysis of the methods is shown in [7]);
- parallelepipeds or prisms with the given dimensions [5, 8].

Despite a sufficient number of works [2-8], where a solution to this problem has been considered, there is no methodological basis for evaluating product design in terms of its rational structural decomposition, taking into account its placement in build workspace. Therefore, to design products suited to determine the rational structural decomposition, it is necessary to develop a special evaluation of manufacturability taking into account the peculiarities of additive technologies.

The main problem is that for geometrically complex products, which are usually manufactured by additive technologies, it is important to take into account the distribution of elementary volumes in space [6]. Existing approaches [4, 9-12] to product decomposition based on the surface analysis of triangulation or CAD-model do not in all cases provide the most rational options for filling a workspace.

In this paper, research hypothesis is proposed that a statistical analysis of the distribution of elementary volumes of products makes it possible to evaluate manufacturability of their design in relation to their structural decomposition, as well as a placement in workspace of installation.

The purpose of this paper is to consider the possibilities of evaluating manufacturability design in the problem of structural reversible decomposition of a product and its placement in build workspace of installation of additive technologies.

The main material

Conducting research was made by using the subsystem of creation and statistical analysis of voxel 3D-model of product. The subsystem is included in a system of technological preparation of materialization of complex products by additive technologies. This system was developed at the department of "Integrated technologies of mechanical engineering" of NTU "KhPI" (Kharkov, Ukraine). The system allows to carry out manufacturability evaluation and analysis of efficiency of a decision of tasks of technological preparation of additive manufacture on the basis of statistical analysis of investigated attributes of voxel, polygonal and layered 3D-model of a product.

The developed subsystem presents following basic options for setting parameters and operating modes with subsequent visualization of the results:

- creation of a voxel 3D-model of product based on a STL-file with regard to the voxels dimensions Δ_X, Δ_Y, Δ_Z;
- saving the voxel model to an ASC-file for analysis in third-party CAD-systems;
- construction of histograms and statistical analysis of distribution of voxels of 3D-model along the X, Y, Z axes and subspaces of workspace;
- determination of basic statistical characteristics (12 parameters) and visualization of analysis results in a form of relative or cumulative distribution.

Usually, when assessing a manufacturability of product, relative indicators are used, which can be adjusted to a range of values $K \in [0,1]$ [13-15]. Taking into account the works [4-6, 10-12], the most representative feature of triangulation 3D-model was chosen. To estimate the predicted efficiency of decomposition of a product for its subsequent placement in the workspace, the following indicator is used [16]:

$$K_V = V_{Part} / V_{Box} , \tag{1}$$

where V_{Part} – volume of product; V_{Box} – volume of a box with the dimensions of the workspace of installation (L_X, L_Y – platform dimensions and H_Z – bild height), $V_{Box} = L_X \cdot L_Y \cdot H_Z$.

For example, for a product in the form of a parallelepiped with dimensions corresponding to the dimensions of platform of selected installation, coefficient $K_V = 1$, i.e. such a product will be the most technological in design, since full utilization of the workspace becomes possible. Also if the dimensions of parallelepiped do not coincide with the dimensions of platform, such a product will have the greatest manufacturability in a case of applying structural reversible decomposition.

The index K_V obtained with dependence (1) allows a preliminary evaluation of the manufacturability of product. However, this does not take into account the spatial distribution of the product material. In practice, products created by additive technologies have complex geometric shapes and complex spatial distribution of material, so the use of dependence (1) will have significant limitations on the applicability. Ideally, when a product is decomposed into N_p-parts, when $N_p \to \infty$ and the minimum permissible distance between a parts $l_{p\,min} \to 0$ then can apply the dependence (1). In practice, increasing quantity of product parts N_p leads to an increase in a laboriousness of reversible procedure (assembly of parts into a whole product), and only up to a certain number N_p, an increase in the value K_V is observed. Therefore, there is a rational number of partitions N_p.

To take into account the distribution of elementary volumes (material) of product in space, the transition from original triangulation 3D model to voxel model was performed. Such a transition provides the possibility of performing a statistical analysis of material distribution over subspaces (parts of a partition) of workspace.

An algorithm for determining the manufacturability of product to evaluate its effective decomposition based on a following assumptions is proposed:

- maximization of occupied volume in workspace of installation;
- multiplicity of subdivision parts into dimensions of platform of a given installation for the same size along Z-axis (direction vector of build);
- number of parts of the workspace partitioning of voxel-free of product model determines the manufacturability level;
- total number of parts of a product must be minimized to ensure less cost when assembling parts into the whole product.

When breaking products in space with its overall dimensions l_X, l_Y, l_Z, will form the subspace containing material and not containing it. Obvious is the influence of the number of empty subspaces N_{V0} on the efficiency of decomposition. With this in mind, proposed the following relation to determine the manufacturability of product (ineffectiveness of decomposition):

$$K_D = 1 - \frac{N_{V0}}{N_p}, \qquad (2)$$

where N_p, N_{V0} – the total number of subspaces and empty (without product material).

As a result, the algorithm for determining the level of product manufacturability includes the following actions:

- formation of voxel model of workspace based on the triangulation 3D model of product based on the voxels dimensions (Δ_X, Δ_Y, Δ_Z) and workspace (l_X, l_Y, l_Z – overall dimensions of product);
- determining the options for partitioning the workspace, taking into account the limitation on partitions number N_p;
- analysis of distribution of the product volume by parts (subspace) of the workspace (fig. 1);
- definition of the index of manufacturability by dependence (2).

Algorithm testing was performed on products models are presented in fig. 2. In Fig. 2 also shows histograms of the distribution of product material according to the subspaces U_i.

When evaluating the manufacturability of product, the workspace was divided into 3^3-10^3 subspaces. This range N_p is sufficient to study its effect on the decomposition efficiency. It is also assumed that the product is manufactured in conjunction with others, so the partitioning was performed on subspaces relative to its own overall dimensions. In production practice, it is preferable to decompose into parts taking into account the platform dimensions of selected installation.

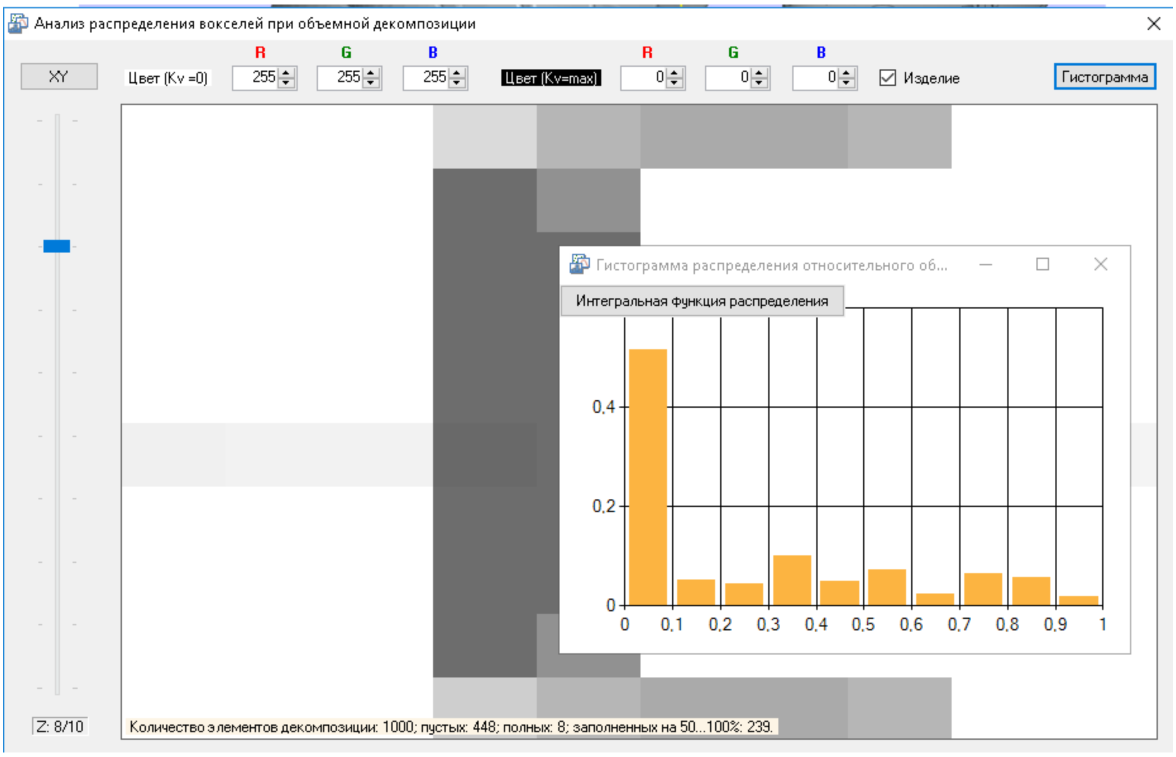

Fig. 1 – The form with visual analysis and histogram of material distribution by subspaces

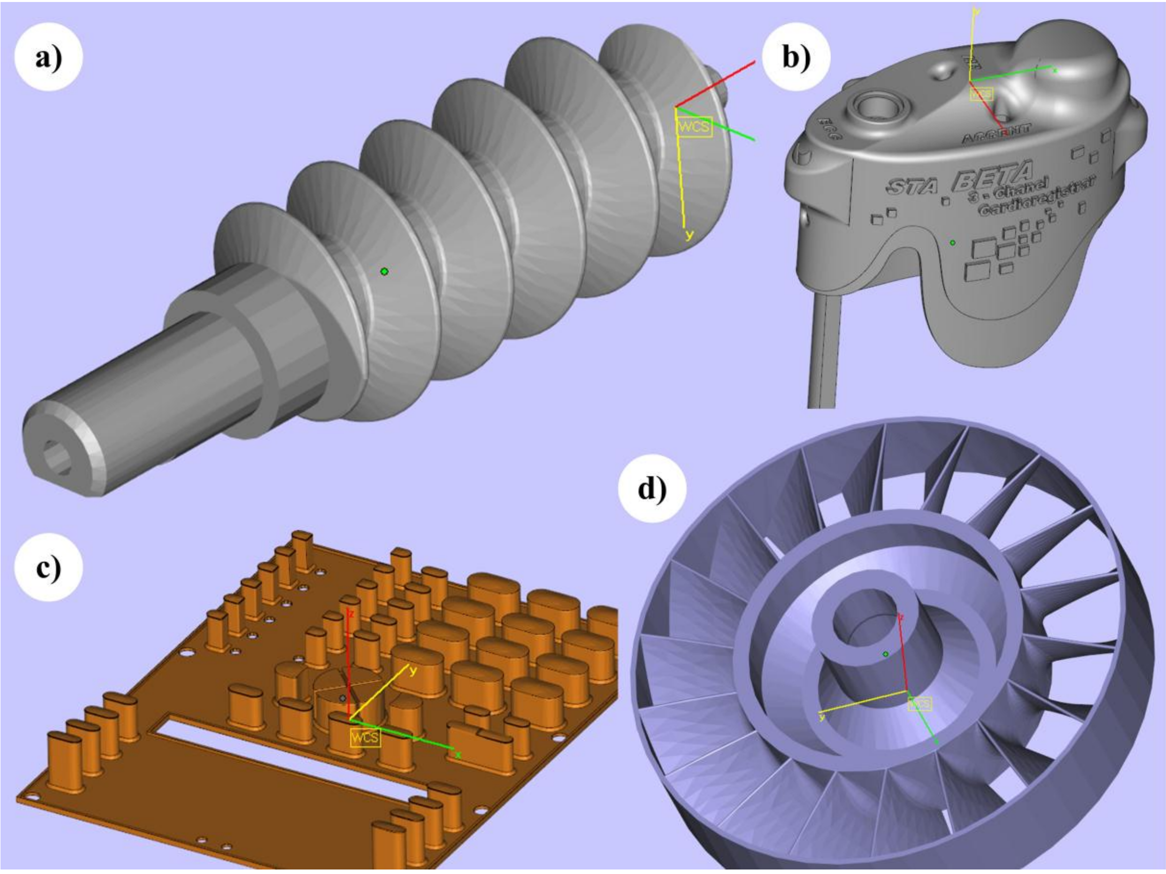

Fig. 2 – Test 3D models of industrial products:
a) screw; b) cover; c) panel; d) ventilator

The calculation results of index K_D for the selected test models (Fig. 2) are presented in tabl. 1.

Table 1 – The results of fitness evaluation of products design for the application of rational decomposition

Test model (overall dimensions, mm)	Number of subspaces U_i			Relative index K_D
	N_p	Empty, N_{V0}	Full, N_{V1}	
Screw (40 × 40 × 144)	1000	333	90	0.67
	125	17	3	0.86
	64	12	0	0.81
	27	0	1	1.00
Cover (84 × 101 × 43)	1000	636	0	0.36
	125	43	0	0.66
	64	18	0	0.72
	27	5	0	0.81
Panel (152 × 196 × 20)	1000	493	0	0.51
	125	36	0	0.71
	64	12	0	0.81
	27	2	0	0.93
Ventilator (26 × 92 × 92)	1000	248	0	0.65
	125	20	0	0.84
	64	12	0	0.81
	27	0	0	1.00

Comparative analysis of the indexes K_D (table. 1) the example of products models confirmed said hypothesis. With the decrease index K_D (manufacturability level) increases the efficacy of reversible structural decomposition of product. The cover and panel have the smallest values of the index K_D, respectively, they are characterized less efficiency of decomposition. This fact is confirmed by industrial experience. Splitting these products on 4-e ($N_p \geq 4^3$) or more parts for each coordinate axes will increase the products density in the workspace by 25÷40 %. Therefore, for these products based on this index is justified for the cases of high demands to the installation workspace filling.

Conclusions

The proposed estimation algorithm and relative index K_V to evaluate the effectiveness of reversible structural decomposition of product allows with a sufficiently high degree of confidence to evaluate workability of industrial product for its manufacture of additive technology.

The results create a methodological basis for evaluating the workability taking into account complex decisions of technological preparation tasks of additive manufacturing.

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